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# NASA TECHNICAL MEMORANDUM

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## AUTOMATIC WELD TORCH GUIDANCE CONTROL SYSTEM

By H. E. Smith, W. A. Wall, and M. R. Burns, Jr.  
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November 1982

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16. ABSTRACT  <p>The objective of this project was to develop a totally new, highly reliable, fully digital, closed circuit television optical, type automatic weld seam tracking control system. Improved automatic tracking equipment is needed, and has been long sought, to reduce weld tooling costs and increase overall automatic welding reliability. This system utilizes a Charge Injection Device (CID) digital camera which has 60,512 individual pixels as the light sensing elements. Through conventional scanning means, each pixel in the focal plane is sequentially scanned, the light level signal digitized, and an 8-bit word transmitted to scratchpad memory. From memory, the microprocessor performs an analysis of the digital signal and computes the tracking error. Lastly, the corrective signal is transmitted to a cross-seam actuator digital drivemotor controller to complete the closed loop, feedback, tracking system.</p> <p>The result of this development is a vastly improved weld seam tracking control system capable of a tracking accuracy of <math>\pm 0.2</math> mm, or better. As configured, the system is applicable to square butt, V-groove, and lap joint weldments. Several innovations have been incorporated which include using algorithms to minimize the effects of stray light reflection, light level changes, erroneous signals, momentary loss of signal, and error causing scratches on the workpiece.</p> <p>A significant advantage of the system is its wide degree of flexibility. Being microprocessor controlled, the software can be readily changed, or modified, to optimize the system's performance for a given set of welding conditions.</p>					
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## TABLE OF CONTENTS

	Page
I. INTRODUCTION .....	1
II. SYSTEM COMPONENT DESCRIPTIONS .....	1
III. SYSTEM OPERATION .....	3
IV. DISCUSSION .....	5
A. Loss of Signal Provisions .....	5
B. Flexible Signal Window .....	6
C. Flexible Decision Level .....	6
D. Scratch Tracking Elimination .....	7
V. SUMMARY OF SYSTEM PROBLEM SOLVING TECHNIQUES .....	7
VI. CONCLUSIONS .....	9

## LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Automatic weld arc guidance control system .....	10
2.	" V monitor .....	11
3.	Typical video signal waveform .....	11
4.	Simplified view of camera, lens, and workpiece .....	12
5.	Tracking window .....	13
6.	Square butt weld chamfering requirement .....	13
7.	Automatic weld arc guidance control unit .....	14
8.	Automatic weld arc guidance translator unit .....	15
9.	Flow chart of automatic weld torch guidance control program .....	16

## TECHNICAL MEMORANDUM

# AUTOMATIC WELD TORCH GUIDANCE CONTROL SYSTEM

### I. INTRODUCTION

To improve automatic welding, a reliable and easily adaptable system for automatic weld seam tracking has long been sought. Several sensing techniques have been attempted, but their practical application has been extremely limited. The development of a universal weld guidance system has not been totally solved, thus far, due to a host of interferences and requirements that are mandatory toward achieving precision welding. Everything from electro-induction transducers, to mechanical feelers, to electro-optical sensing means have been tried. No sensing technique seems to be totally adequate. Examples of the most troublesome problem areas are the aerospace requirement of noncontact sensing, material holddown clamp interference, weld joint upset, sensor proximity changes, magnetic characteristics of the material and fixturing, momentary loss of signal, intense weld heat, surface scratches, weld joint preparation, thermal expansion, and interference with tooling and equipment peculiar to the different weld processes.

Of all the techniques attempted, closed circuit television (CCTV) seems to hold the most universal promise. As a result, a Marshall Space Flight Center Director's Discretionary Fund applied research project was proposed and initiated in 1979 to develop a reliable and more accurate, fully digital, automatic weld seam tracking system. The system proposed and developed features a Charge Injection Device (CID) digital CCTV camera combined with microprocessor control. This state-of-the-art combination of sensing and control overcomes many of the adversities which previously severely limited the use of weld guidance control systems. For instance, the capacity to make complex real time decisions significantly improves the system's performance.

The result of this development effort is a reliable weld torch guidance system capable of tracking accuracies of  $\pm 0.2$  mm, or better, on square butt, V-groove, and lap joint welds. Because of many unique features of this development, a patent application has been filed.

Highlights of this new system, and how reliability is achieved, is discussed in the following sections.

### II. SYSTEM COMPONENT DESCRIPTIONS

The major goal of this project was to improve overall weld seam tracking performance. This was accomplished by providing a better defined tracking signal, by incorporating a more accurate and reliable control system, and by solving, or minimizing, inherent problems encountered on earlier seam tracking system developments. The adverse effects of many of the prior problem areas were minimized by initial planning including the types of system components selected. Figure 1 is a block diagram of the system and Figures 7 and 8 are photographs of the prototype operation system.

There are two primary subsystems which vastly increase the reliability and tracking accuracy of this newly developed system. One subsystem is the use of a digital CID solid state CCTV camera as the seam tracking intelligence sensing element. The other major subsystem is the microprocessor controller whose mathematical analysis capability is a major contributor.

The complete guidance and control system is composed of the following major components and subsystems as reference to Figure 1:

1. A Commercially Available CID Solid State CCTV Camera (1), Lens (2), Camera Controller (?), and Video Monitor (4).

The unique features of this CID camera system are its array of solid state individual light sensing video elements, called pixels, and its digitized video output in an 8-bit parallel word format. Digital video output is at a 4.5-megahertz rate and is used by this seam tracking development for signal analysis and system control. Video information is obtained from the level of light impinging on each of the more than 60,000 light sensing elements. When the CID TV camera is in operation, a voltage potential is set on each pixel which is dependent on the instantaneous light intensity impinging upon that pixel. Through conventional scanning means, each pixel is sequentially scanned and its electrical equivalent of the light level digitized as an 8-bit parallel word. This 8-bit word is then placed on output lines as signal data. There are 244 rows of 248 pixels each on the camera's 16-mm format solid state sensor. Since each pixel is spatially fixed, reliable geometric accuracy and stability for control applications is assured.

2. A Specially Developed Signal Control Subsystem Which Is Composed of the High Speed Buffer Memory (6), Buffers (5 and 7), High Speed Memory Select Circuit (8), and Control Circuit (9).

This interfacing circuitry development was necessary because the 4.5-megahertz digital data output of the CID camera controller is much too high in frequency to transfer data to the slower microprocessor in real time. Therefore, it was necessary to develop a high speed buffer memory and memory control circuit to receive and temporarily store data from the CID camera system. Since only one horizontal line of pixels per field is used to obtain tracking data, the control circuit automatically selects the correct line of pixels for interrogation and stores data from each pixel of that line in buffer memory. The microprocessor then transfers this data to system memory, when needed. It then releases the high speed control circuit to obtain, and store, updated data from the same centrally located horizontal line of pixels. Data is thus updated every 33 msec (every other vertical sync pulse).

3. A Standard 8080 Microprocessor System (10).

The 8080 microprocessor system is used for data analysis, decision making, and central control.

4. A Commercially Available Digital Stepping Motor (12) and Stepping Motor Controller (11).

The digital motor and controller is used for cross-seam control and was chosen for its precision control capability. Each pulse to the motor rotates the shaft 1.8 deg and each complete rotation of the shaft moves the cross seam actuator 1.59 mm. Therefore, each pulse to the motor moves the cross seam actuator 0.0079 mm.



The motor controller is programmable to generate from 1 to 255 pulses to the digital motor for each control pulse input. For this application, the controller is programmed to generate 6 motor pulses for each control pulse, which is approximately the distance between pixels.

#### 5. A Non-Coherent, Fiber Optic Light Source (23).

Background illumination is not critical. However, a fiber optic cable to supply the illumination was considered ideal for this application due to the uniformity of its light output and small cable.

#### 6. A Mechanical Cross Seam Actuator (24).

### III. SYSTEM OPERATION

To generate the tracking signal, the camera and lens are mounted perpendicular to the workpiece, focused, and approximately aligned with the joint. The camera field of view is magnified through the lens system before impinging on the pixel array per Figure 4. By illuminating the viewing area with extra background light, a typical joint image (Fig. 2) is displayed on the monitor. This particular type image is due to both the camera lens and the illumination source being perpendicular to the workpiece. Joining edges of the two weldment sections will reflect very little light into the camera and are displayed as a dark line on a video monitor. Light from the reflective metal surface is displayed as the white background. Thus, the black stripe (Fig. 2) is the weld joint whose width depends on the width of the weld joint chamfer, or gap. Each pixel has an 8-bit digital output with a theoretical maximum resolution of 0 to 255 (shades of gray) to indicate light intensity. Zero is the darkest, no light, and 255 the brightest.

Since the CID camera is not a standard television camera, the TV controller was designed to output a video format to function with a conventional television monitor requiring two interlaced fields of 262 horizontal video lines. Each field is triggered by a vertical sync pulse every 33 msec with each video line being triggered by a horizontal sync pulse. These two sync pulses are generated by the camera controller and are used as the control signals for taking tracking data. Because the CID camera has only 244 horizontal lines of pixels, each line is displayed twice in sequence and the remaining 18 lines are blanked (Fig. 2). This scheme thus provides the required 262 lines per field.

Since there are only 232 active pixels per horizontal line, the other 16 are purposely blanked by the camera controller. To calibrate the system, it is only necessary to place a millimeter scale along the horizontal viewing area of the camera. From the TV monitor, the width of the viewing area can be read. This width divided by 232 will determine the distance between pixels in millimeters. All system measurements and corrections are thus referenced to numbers-of-pixels.

For prealignment, it is only necessary to see the weld joint image on the video monitor. A software program, called preweld alignment loop, will automatically align the torch with the joint upon command. The system will search the entire viewing area and select the widest dark area as the joint. To begin the preweld alignment, a vertical sync pulse enters the control circuit setting a counter circuit. Each horizontal sync pulse is then sequentially counted. At horizontal sync pulse number 128, in

approximately the center of the camera pixel array, the control circuit opens gates of the memory select and buffer circuits. This allows one line of data to fill the next 256 high speed memory locations with 8-bit data words. There are 24 of these data words that are purposely blanked to coincide with the 232 active pixels per horizontal line. Therefore, only data from 232 pixels are available to use in the tracking signal calculations. The next horizontal pulse closes the gates and sets a flag to signal the microprocessor that data have been received. When the microprocessor completes the data analysis on the last data cycle, it opens the control gates of the buffer and memory select circuits and allows one line of data to be transferred into the main processor memory. Gates to buffer and memory select circuits are then closed and the control circuit is set to obtain another line of data when triggered by another vertical sync pulse. Data is taken every other vertical sync pulse to utilize the same horizontal line position on the camera pixel array.

After the preweld alignment mode, this system has two modes of tracking operation, the initial tracking alignment mode and the final tracking mode. During the preweld and initial tracking alignment modes, there is no calculated light level reference value to compare with new data to locate the weld joint. Therefore, a digital binary value of 20 is placed in memory and used as a reference. The binary value of 20 was determined from test data that indicated good signal data for the joint must be below this value. As each data word is transferred to the microprocessor register, it is compared with the reference value. Any data above 20 is a logic 1 and data below 20 is a logic 0, or weld joint.

When the joint image is located, the system will then determine the number of corrective motor drive pulses required to align the torch with the center of the joint. This is accomplished by calculating how many pixels the center of the image is from the reference pixel on the horizontal data line. For this system, the reference pixel chosen is number 116 which is approximately the center of the horizontal data line. Adjustments are then made to correct and maintain torch alignment with the center of the joint. The signal generated by the one horizontal line of 232 pixels will be similar to Figure 3. Relative darkness and lightness of the signal will depend on the amount of illumination and the reflective surface.

After the initial alignment cycle is completed, the system automatically transfers to the final tracking mode. At this time, a reference light level value, called flexible decision level (Fig. 3) is calculated and stored in memory. This calculated reference level replaces the binary 20 reference in the above initial alignment mode. The tracking reference light level is determined by calculating the average of the white pixel digital values and the average of the dark, or joint, pixel digital values. Then the microprocessor calculates the average between these two values as the flexible decision level. Each tracking signal data word input is compared to this value. Any data above the decision level value is a logic 1, or background light, and any data below the decision level value is a logic 0, or weld joint. Continually updated every 48 data cycles, this decision level value compensates for any changes in illumination, or workpiece, reflectance. This decision level value is also displayed as a hexadecimal number on the front panel of the motor controller for visual monitoring.

Another visual display is the tracking indicator light located in the same display with the decision level value. The purpose of this light is to give the operator a visual indication when the system is tracking the joint. During tracking, this light is on, and when tracking operation stops, the light immediately turns off.

While in the tracking mode, damaged areas on the workpiece may cause erroneous data to be generated. To eliminate this possibility of using false data from a scratched, or pitted area, only data from a small viewing area on either side of the joint is used to calculate tracking data. This flexible window technique is accomplished by first calculating the joint width and then adding to this value twice the average error correction value plus 12 pixels (6 pixels either side of the joint). The microprocessor only reads data from this small number of pixels to calculate further tracking data.

In summary, for each horizontal line of data (232 pixels) placed in the high speed memory, the microprocessor calculates the weld joint width, the error correction, the average of the last eight error corrections, and a new tracking signal window width. It stores these values in RAM memory. New data is compared to stored values by the microprocessor to make sure the new data is valid before making any corrections or updating stored values. If the new data is valid, the error signal correction is fed to the drive motor controller which sends the required pulses to the drive motor to move the weld torch to the center of the joint. If the error correction is more than the average of the last eight error corrections, plus four pixels, the system will consider this as erroneous data, make an error correction equal to the average error of the last eight data cycles, and then input another line of data. For each erroneous data cycle, the flexible window will open in increments to search for the joint until the complete viewing area is utilized. A valid data signal will again close the window.

This automatic weld arc guidance system, as configured, will only guide a torch along a relatively straight joint. This is because the signal sensing element and the weld torch head are mounted on the same actuator in a fixed position relative to each other. By utilizing separate actuators for the signal sensing element and the weld torch head, the microprocessor is capable of accurately controlling the weld torch along nonuniform curved joints by using the method of delayed data feedback. This can be accomplished by storing in real time both travel speed and data in memory. The system would then output the data to the torch head controller at the correct time to maintain tracking along the weld joint. Also, this delayed feedback system could be used for multipass welding by using a permanent type storage and replay.

A significant advantage of this new weld guidance system is its wide range of flexibility. Being microprocessor controlled, the software can be readily changed, or modified, to optimize the system's performance for a given set of welding conditions. For a general understanding of the software functions, review Figure 9.

#### IV. DISCUSSION

This section consists of an explanation of the most important new features of the tracking system. These features, along with the CID camera, increase the reliability and accuracy of this system as compared with prior automatic seam tracking system developments.

##### A. Loss of Signal Provisions

One of the major problems with prior art optical, and CCTV, systems was the loss of tracking with a temporary loss of signal. Since this system has a microprocessor

with memory, it is capable of comparing data and making decisions. A continuous average of the last eight error corrections is maintained in memory. If the signal is lost, the system will make the average error correction to continue tracking on the same general path. This average error correction will continue for a preset number of data cycles unless a good tracking signal is received. If no tracking signal appears during the preset number of data cycles, the system will stop the tracking operation and output a signal to shut down the torch travel and weld power systems. This tracking feature vastly improves the reliability of the CCTV tracking system. Also, the microprocessor makes a comparative check with each tracking signal received. If the data are not within a preprogrammed tolerance, the system will treat the tracking signal as missed data and make the average error correction to maintain the same travel path. Typically, the system will travel down the average path and shut down in approximately 1 sec if the tracking signal is not reinitiated.

### B. Flexible Signal Window

Another important feature incorporated in this system is the flexible tracking window. This feature forces the system to ignore the surface condition of the material (scratches, pitted areas, spots, etc.), except those very near the joint. When the system first begins tracking, it automatically locks onto the joint. At this time the viewing area utilized in the computation of tracking data decreases to a very small area either side of the joint.

This window effect is accomplished by using the microprocessor to first compute the joint width. Then twice the average preprogrammed error correction is added to the joint width. To this combination, a predetermined number of pixels is added which is dependent on the allowable skew rate and the maximum amount of correction desired. For demonstration purposes, the window for this development system is programmed to close to approximately 0.4 mm either side of the joint (Fig. 5). This window serves two purposes. First, the system operates much faster because, once initialized, data is taken only from the small area within the window. Second, any problem areas outside the small window will not affect the tracking reliability of the system.

After this window has been calculated and closed, it will stay closed for the duration of the weld unless missed, or erroneous, data is obtained. If the weld joint is lost and not immediately located, the window will open a preset increment each data cycle until the full viewing area is searched. During this opening process, the window will reclose at the end of any cycle when true data is again obtained. From this small window, tracking data is calculated and updated each data cycle. This flexible window technique minimizes the chances of a tracking error due to changes in the surface condition of the material or to extraneous reflected light.

### C. Flexible Decision Level

In earlier CCTV systems, illumination adjustment was critical in both intensity and angle of incidence. Also, any change in light intensity or reflective surface of the material created possible problems due to a change in the detected tracking signal. This problem has been solved by the flexible decision and updating its value.

Only the pixels inside the flexible window are used to calculate tracking data. From this small group of pixels, the average of the light pixel digital values and the

average of the dark pixel digital values is calculated. Then the digital value of the midpoint between these two averages is calculated as the new decision level. When received, the digital signal data is either a logic 1 or a logic 0. Any signal data above the decision level value is a logic 1, or background. Any signal data below the decision level is a logic 0, or weld joint. Since the decision level is continually calculated and updated, any reasonable change in the illumination, or reflected light, will not affect the tracking signal.

#### D. Scratch Tracking Elimination

Features were designed into the system that minimize the possibility of moving off the weld joint and tracking a scratch, or indentation, in the surface of the material. First, for a scratch to interfere with tracking, it must be within the small tracking window. The two most important features to minimize this problem are the preset maximum number of pixel corrections and the preset minimum pixel joint width the system will track. The maximum number of pixel corrections is set according to the desired tolerance. If the system attempts to make a correction of more than the allowable number of pixels, the microprocessor will take this data as erroneous and make a correction equal to the average of the last eight data cycles. This average correction will continue the torch along the same path.

By presetting the minimum joint width, the system will ignore any scratches, or indentations, that are less than this value. When tracking a V-groove, the joint is wide enough that all normal scratches can be ignored. Problems can occur with square butt joints where small scratches may be wider than the joint. This condition would be a problem only when the scratches are very near the joint and run parallel, or almost parallel, to the joint. To avoid this problem, edges of the butt joint can be slightly chamfered. Chamfering will make the butt joint appear wider and allow the minimum tracking width to be increased. Thus, small scratches are ignored.

Because of this possible problem with square butt joints, a prototype handheld tool was developed to chamfer the edge of the workpiece as described in Figure 6. This tool allows a small chamfer to be easily, and quickly, cut on the edge of the material which would have minimal effect on welding. This is especially true with the new Variable Polarity Plasma Arc (VPPA) technique of welding, since cut or ragged edges no longer cause aluminous porosity.

#### V. SUMMARY OF SYSTEM PROBLEM SOLVING TECHNIQUES

Summarized herein are the salient features of the new automatic weld seam tracking development and the primary contributions of each feature relative to improved performance over prior art in this area of technology.

##### 1. Use of the CID type CCTV digital camera system improves:

- a. Black-to-white definition where very bright objects are surrounded by a dark background. This feature results in significantly reduced blooming, or wash-out, of critical video signal data.

- b. Seam tracking intelligence signal resolution due to the 8-bit digital video signal.

c. Signal-to-noise ratio.

d. System accuracy due to the fixed placement of the solid state pixel light sensing array which replaces the hitherto used electron beam type camera Vidicon tube.

2. Placement of both the CCTV camera and background illumination source directly above the weld joint, as required, to minimize the adverse effects of:

a. Weldment holddown fixturing.

b. Sensor-to-work proximity changes.

c. Magnetic characteristics of both the weldment material and fixturing.

d. Weld arc heat and intense light.

e. Weld joint varying upset wherein flatness of the weld joint is not uniform.

3. Automatic flexible electronic window feature reduces the adverse effects of:

a. Scratches, pits, and nonhomogeneous surface finish of the weldment material.

b. Extraneous reflected light.

4. Automatic flexible digital logic decision level feature minimizes:

a. The amount of necessary background illumination.

b. Effects of changes in weldment surface reflectance.

c. The criticality of background illumination stability.

5. Path averaging solves many of the problems associated with:

a. Momentary loss-of-signal.

b. Tracking over track welds.

c. End-of-weld closeout error due to loss of signal.

6. Preset tracking tolerance helps minimize:

a. False tracking of skewed scratches.

b. Tracking error.

7. Digital motor and motor controller improves:

a. System accuracy.

b. System stability.

c. Predetermination of system behavior should performance values require change.

## VI. CONCLUSIONS

The result of this Center Director's Discretionary Fund development is a vastly improved weld seam tracking control system. A tracking accuracy of  $\pm 0.2$  mm is a factor of 2 to 3 times better than prior systems developed at MSFC, and the system is also very flexible from the standpoint of controls. Being microprocessor controlled, the software can be readily changed, or modified, to optimize the system's performance for a given set of welding conditions.

During the initial planning stages of this project, a set of desired performance goals were proposed. These goals were (1) develop a fully digital and reliable system, (2) provide sensed centerline tracking accuracy of at least  $\pm 0.81$  mm, (3) measure sensed joint width to at least  $\pm 0.81$  mm, (4) provide video output for user monitor, (5) software provision for delayed, or replay, of joint tracking, and (6) system be applicable to square butt, V-groove, or fillet welds. All these initial performance goals were either met or exceeded. Tracking accuracy and joint width measurements are both to an accuracy of better than  $\pm 0.2$  mm.

Using the prototype translation system presently available for tests, a skew (cross seam) rate up to 10 mm/sec can be achieved. It is estimated that this skew rate is sufficient for more than 98 percent of all weldments made with automatic weld systems. However, this rate may be increased by utilizing a faster response translator system.

For some applications, especially VPPA as well as TGA (TIG) welding, a delayed feedback feature will be required. Such a feature allows the signal sensor to obtain tracking data well ahead of the welding arc and feed the corrective position data, at the correct instant, back to the weld head position controller. In this type welding, the wirefeed mechanism almost always makes it impossible to mount the camera as near the welding arc as desired. Since most welding for spacecraft is accomplished with the fillwire process, it would greatly enhance automatic tracking if the camera were mounted in a convenient location ahead of the wirefeed. Therefore, plans are now underway to develop the delayed feedback feature and incorporate it into the existing prototype automatic-weld tracking system for test and demonstration purposes.

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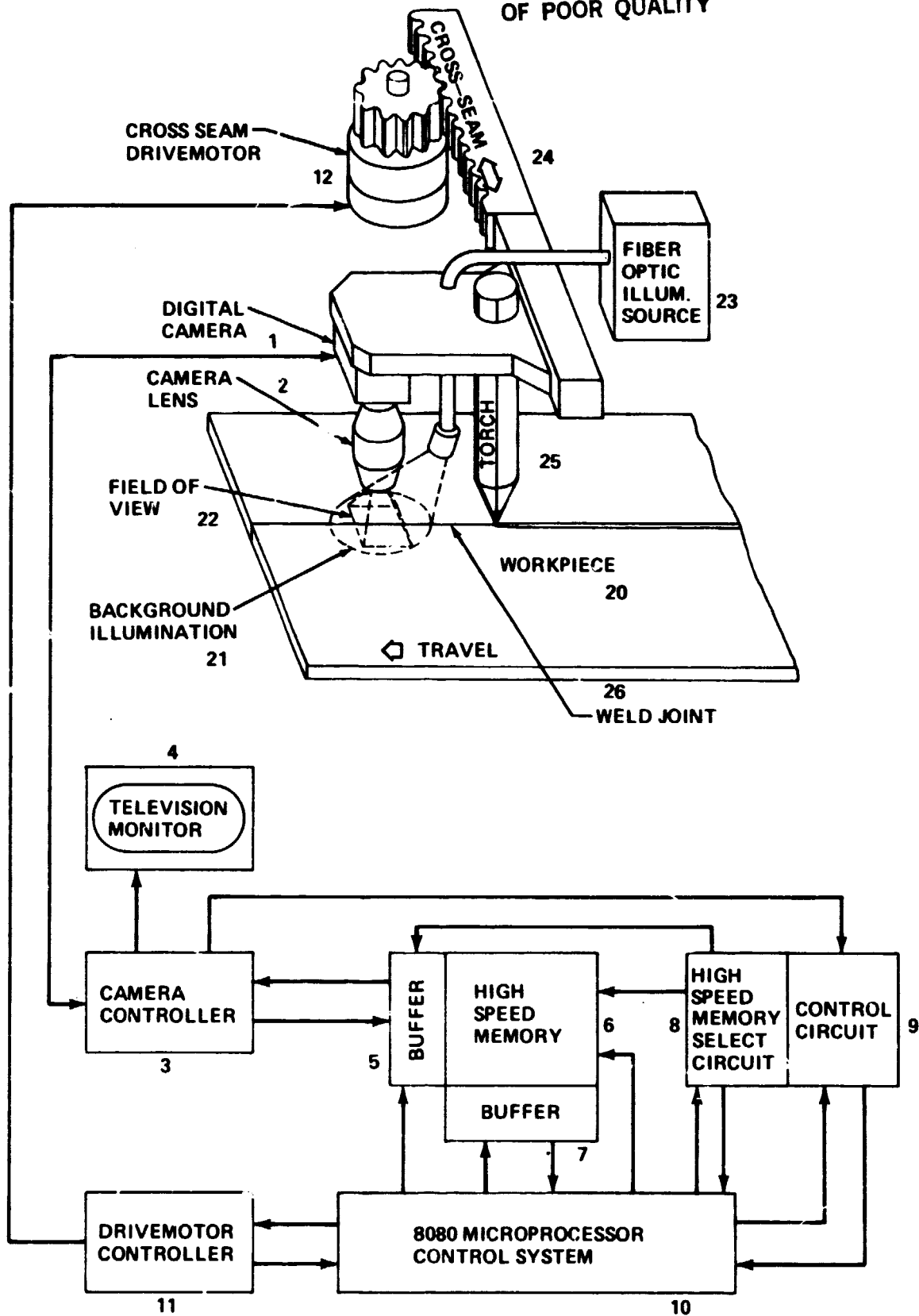


Figure 1. Automatic weld arc guidance control system.



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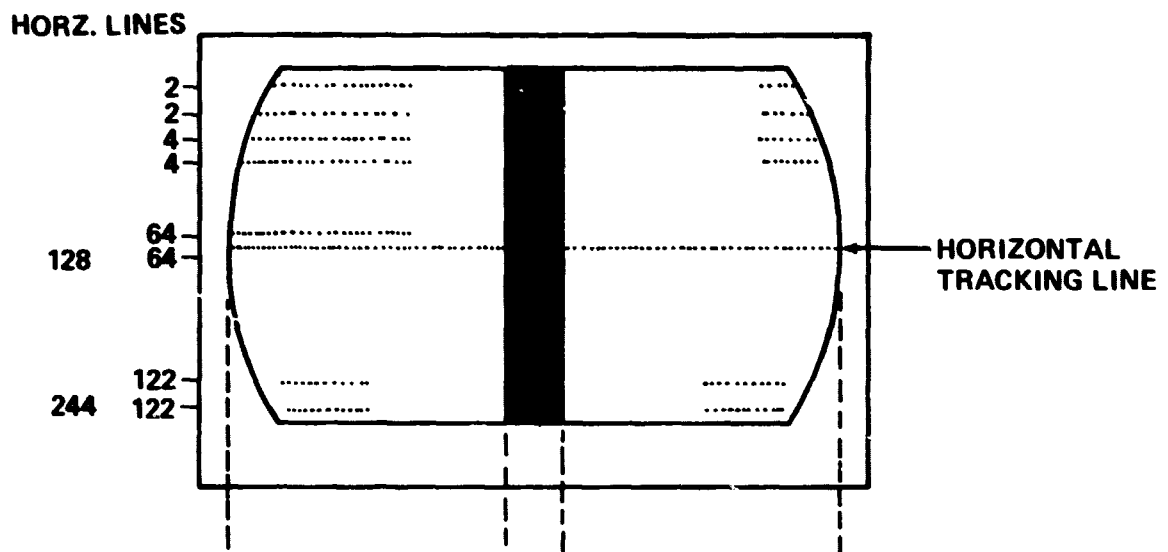


Figure 2. TV monitor.

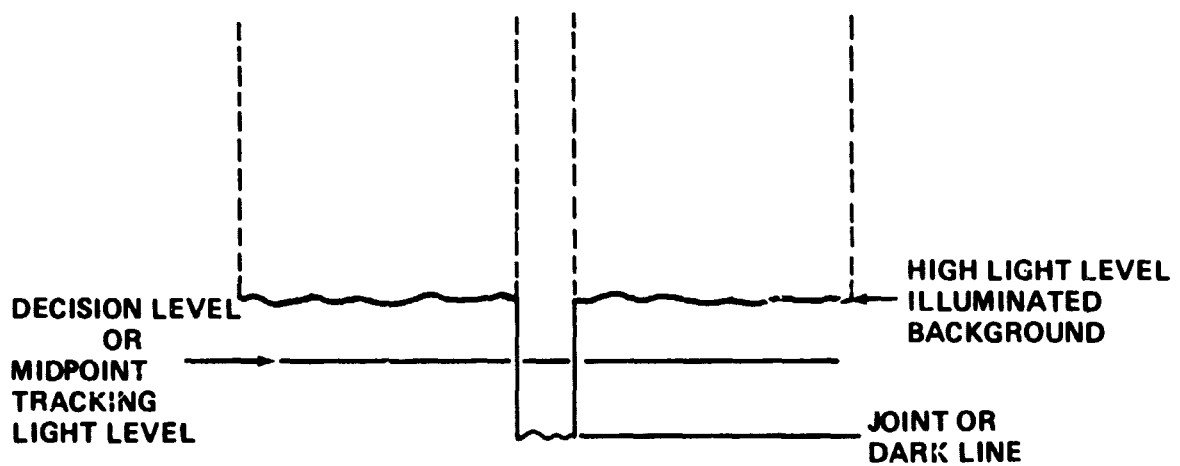


Figure 3. Typical video signal waveform.

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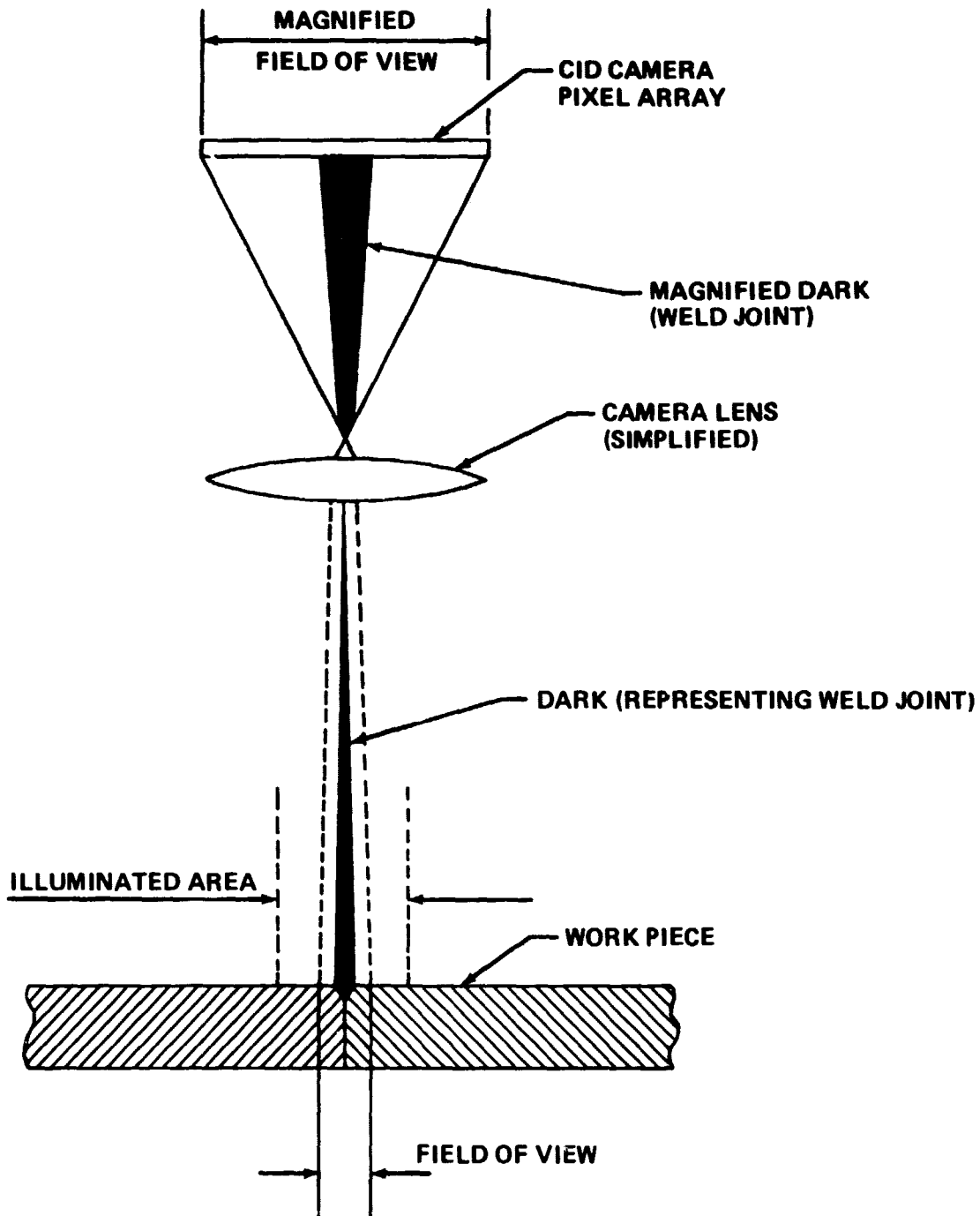


Figure 4. Simplified view of camera, lens, and workpiece.

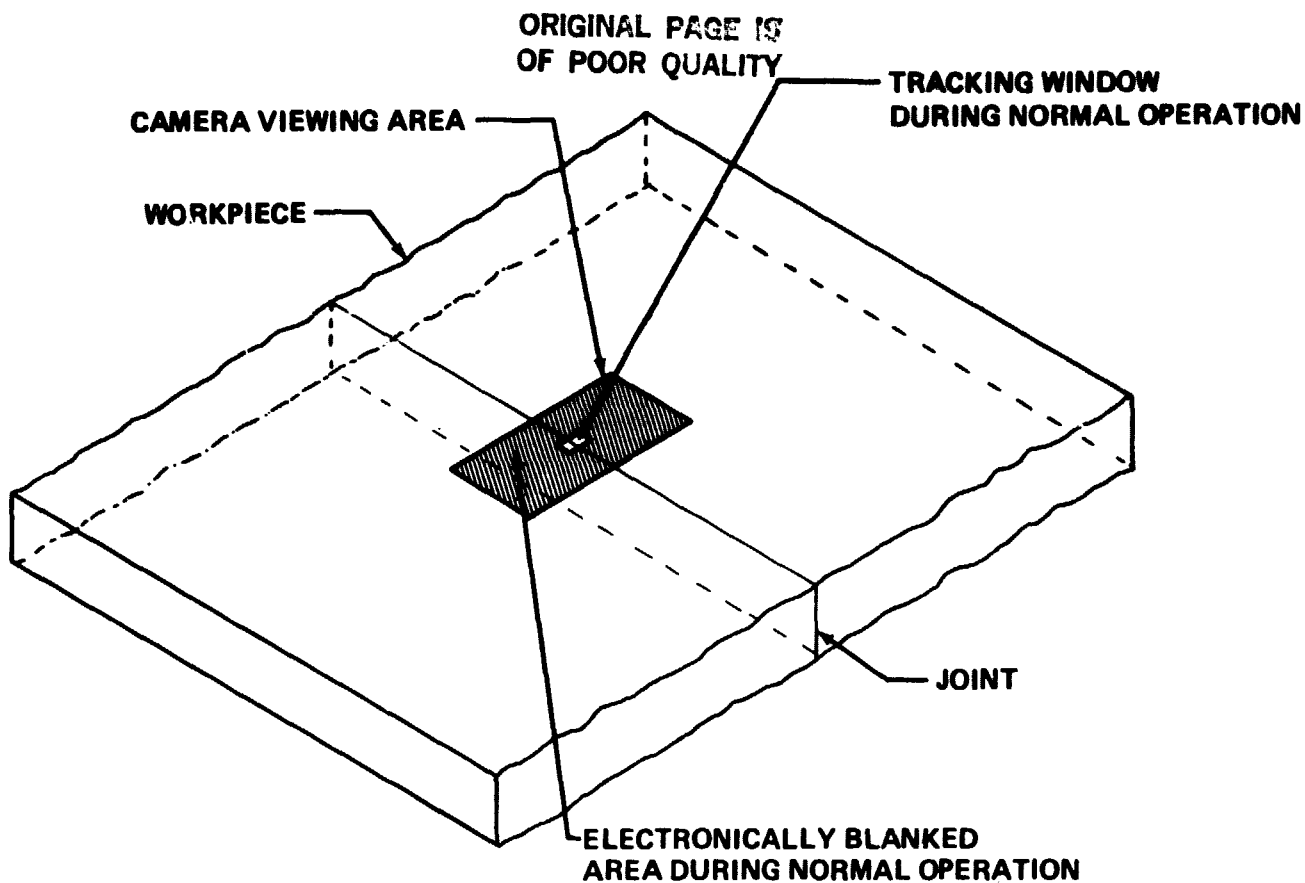


Figure 5. Tracking window.

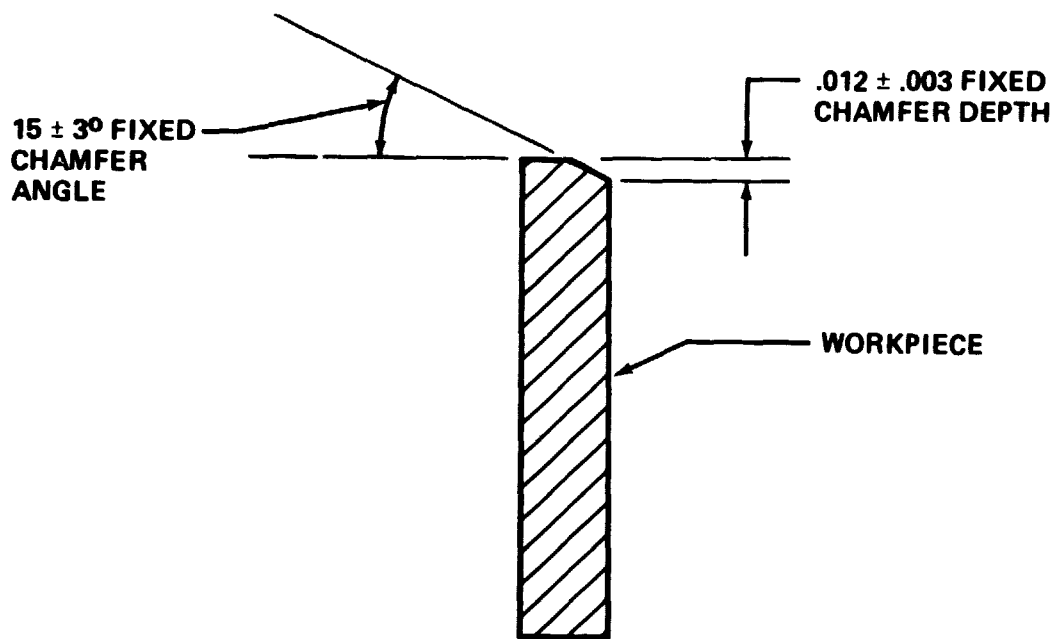


Figure 6. Square butt weld chamfering requirement

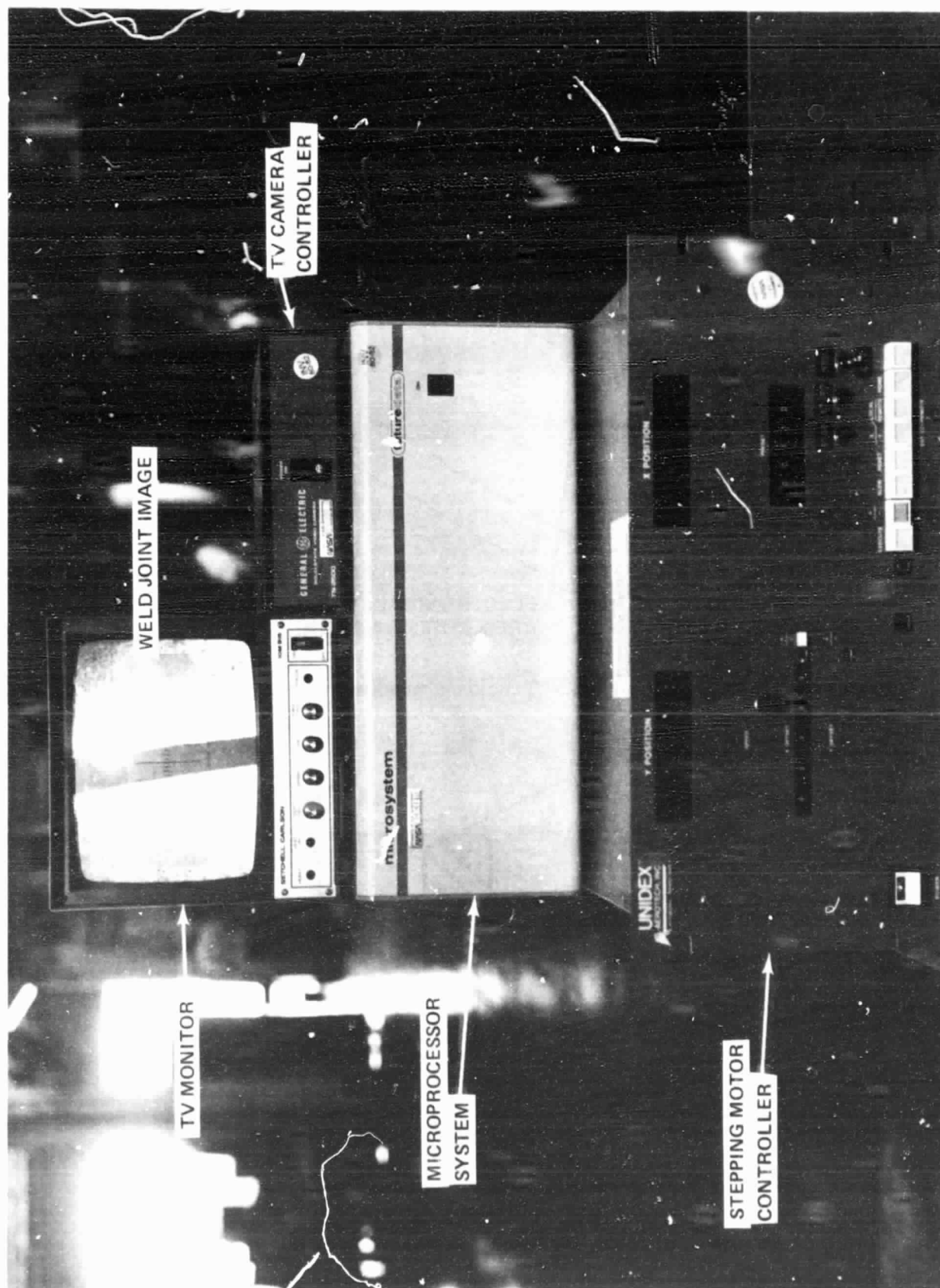


Figure 7. Automatic Weld Arc Guidance Control Unit

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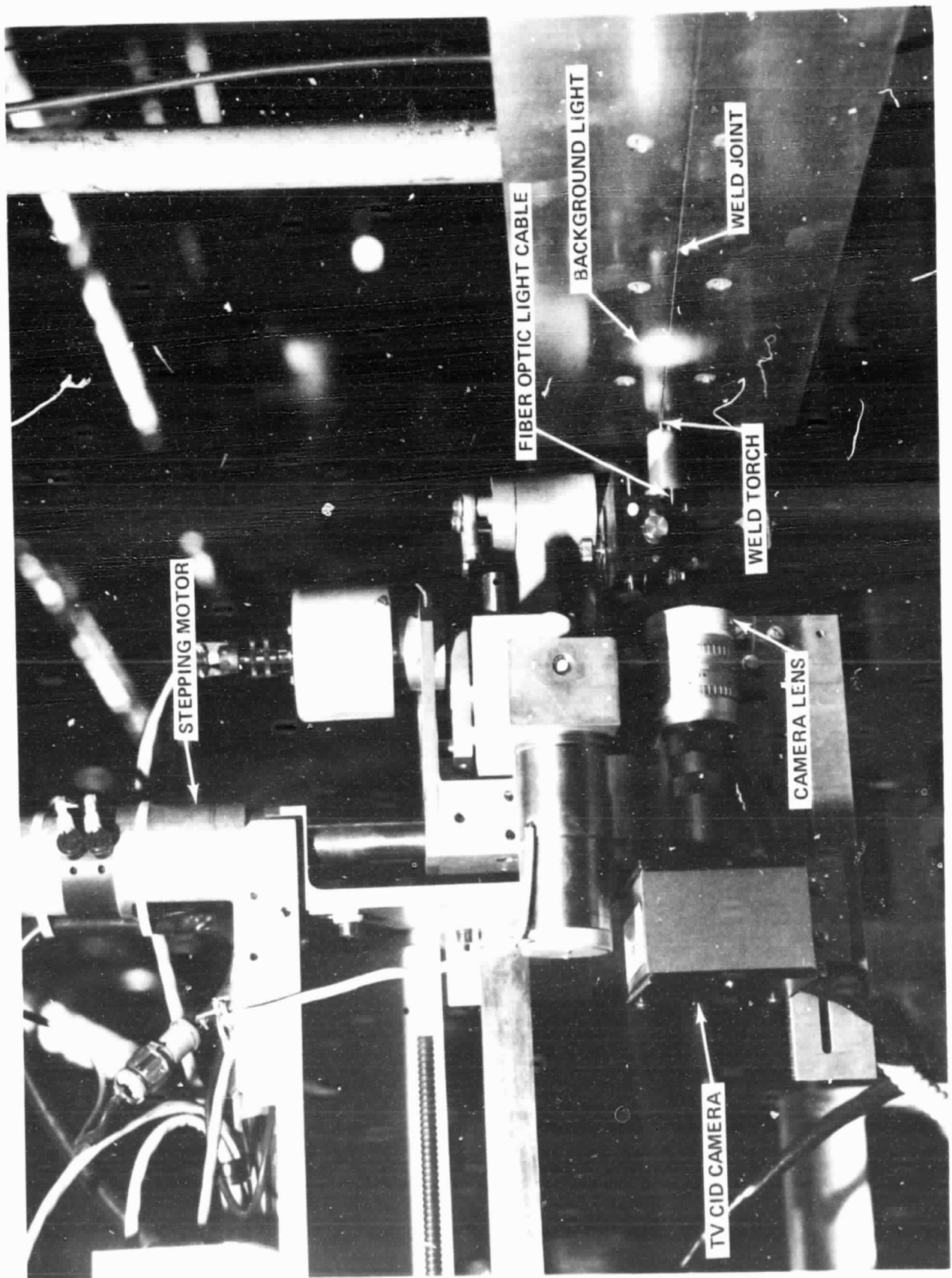
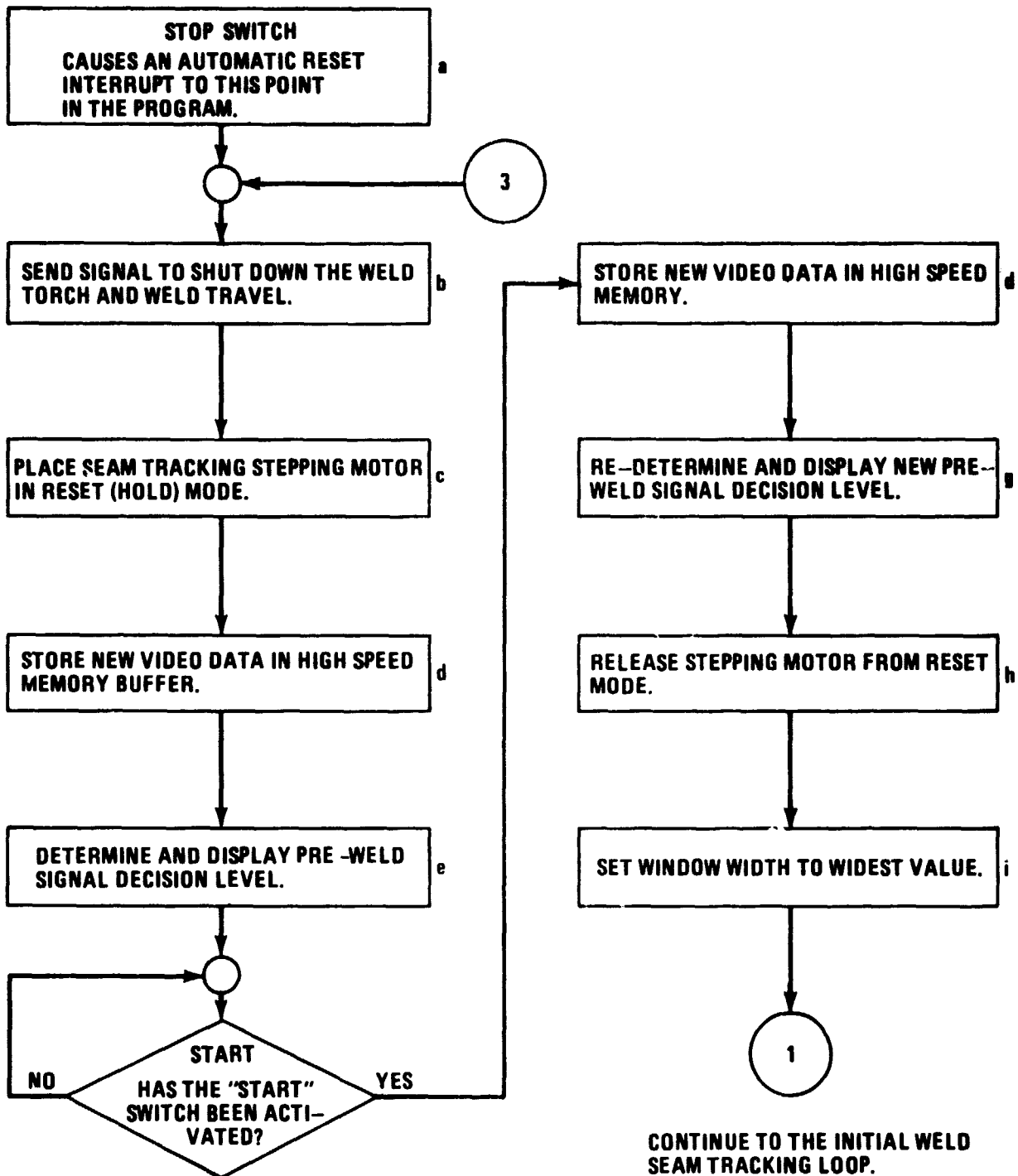


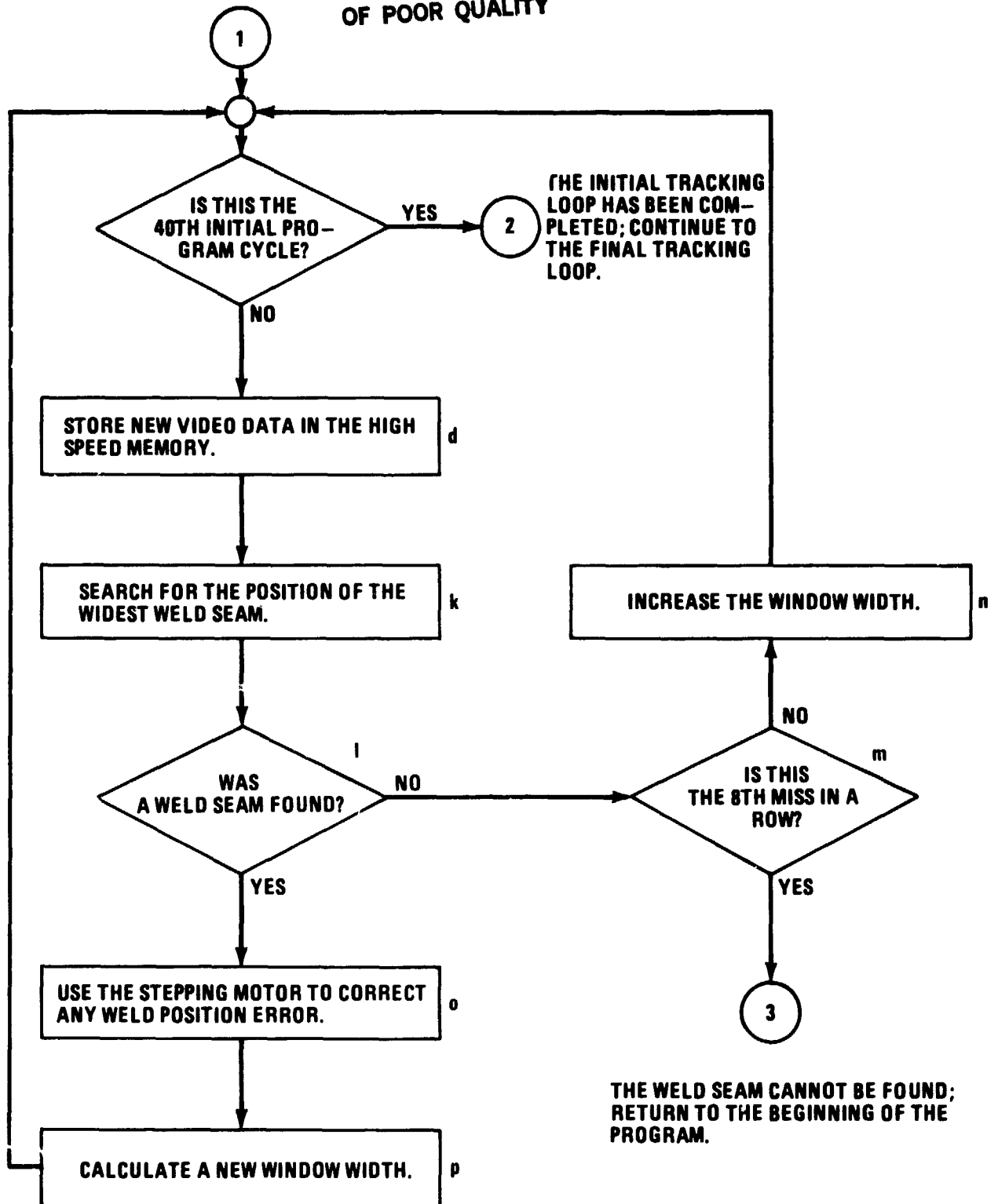
Figure 8. Automatic weld arc guidance translator unit.



a. Preweld alignment loop

Figure 9. Flow chart of automatic weld torch guidance control program.

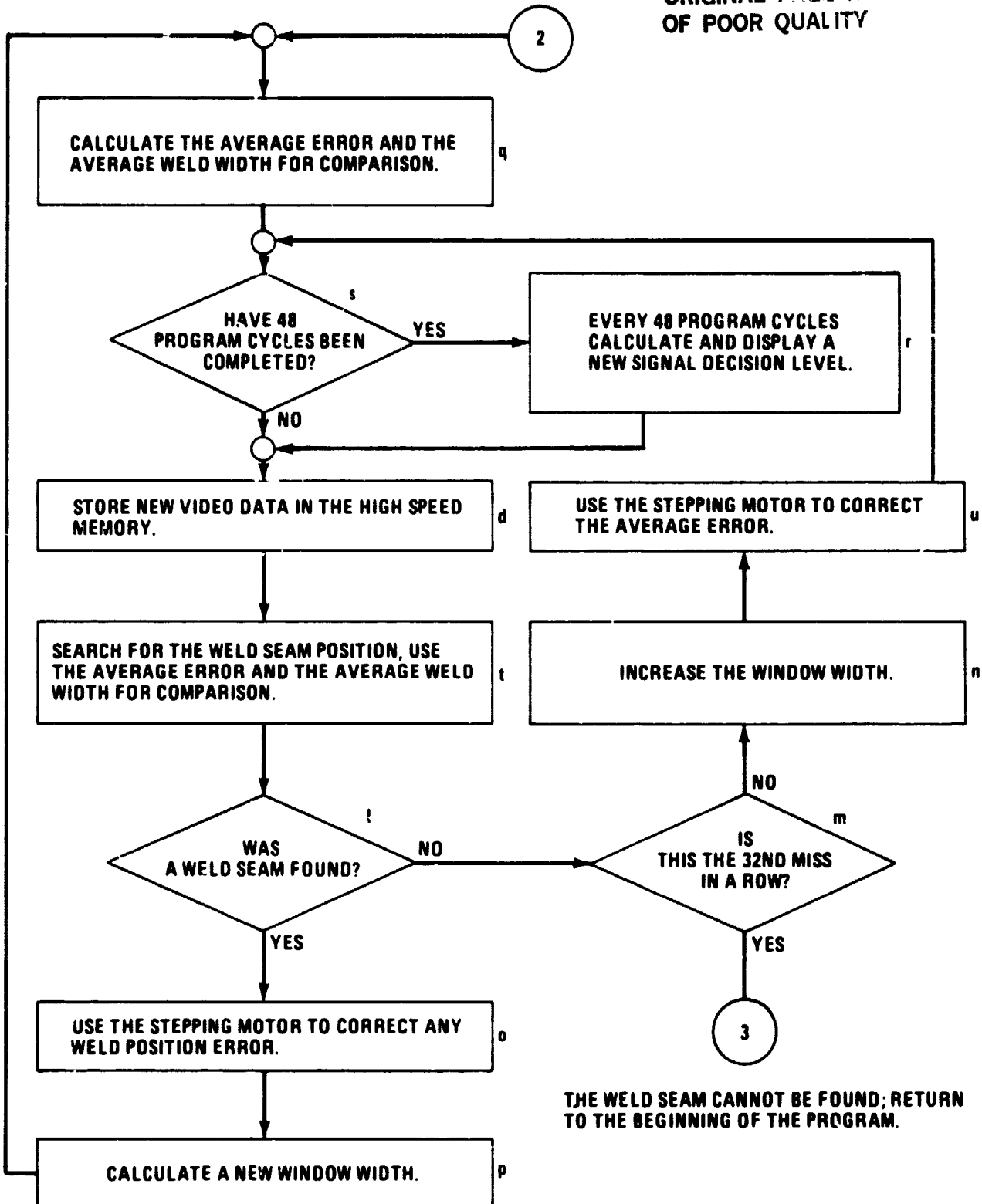
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b. Initial weld seam tracking loop.

Figure 9. (Continued).

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c. Final weld seam tracking loop.

Figure 9. (Concluded).




APPROVAL

AUTOMATIC WELD TORCH GUIDANCE  
CONTROL SYSTEM

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

  
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